Charles Darwin University

Final Examination

Family Name						
Given Name/s						
Student Number						
Teaching Period	Semester 2, 2017					

ENG482 – Engines and Turbomachinery	DURATION	
	Reading Time:	10 minutes
	Writing Time:	180 minutes

INSTRUCTIONS TO CANDIDATES

The examination has two sections.

Answer all questions in both sections. Marks as indicated.

Note: Questions are not of equal value.

Read all questions carefully and commence writing when instructed.

EXAM CONDITIONS

<u>You may begin writing from the commencement of the examination session.</u> The reading time indicated above is provided as a guide only.

This is a CLOSED BOOK examination

Any non-programmable calculator is permitted. No data storage devices are permitted.

No handwritten notes are permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
No additional printed material is permitted	2 x 20 Page Book 1 x Scrap Paper Formula Sheet/s

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Section A

A detected description with diagrams (if necessary) is required in this section.

You must explain your answers fully.

Total Number of Marks for this section: 50%

Question 1 (15%)

Consider the emissions of primary concern from SI engines.

a) What are they?

(2%)

b) List 5 aspects of engine design or operation that can help minimize emissions, briefly explaining how this is achieved for each.

(5%)

c) How does EGR affect emissions? Mention each type of emission in your answer.

(3%)

d) What are the two main parameters that affect the efficiency of a catalytic converter? Provide ideal values of these parameters for maximizing efficiency, and briefly mention how deviations from ideal will affect converter efficiency / condition.

(5%)

Question 2 (10%)

Consider a carbureted SI engine operating at 2000 rpm under constant load. The engine has been operating long enough to have achieved steady-state temperatures.

a) Rank the following in order of lowest to highest temperature:

- Exhaust valve
- Piston face
- Exhaust gas
- Cylinder wall
- Spark plug

(2%)

b) The engine speed is increased by reducing the load. It is observed that the rate of heat transfer from the combustion chamber in kW is slightly increased. Does this mean that indicated thermal efficiency is decreased? Explain your answer.

(3%)

c) The load on the engine is now increased above its original setting, but the throttle is opened further to keep speed constant at 2000 rpm. State the expected impact on (i) engine temperatures, (ii) total heat loss per cycle, and (iii) indicated thermal efficiency. Give reasons to support each claim.

(5%)

Question 3 (10%)

Vehicles use a variety of engine types for their propulsion, including piston and gas turbine engines.

a) Compare the approximate efficiency ranges achievable with gas turbine engines versus piston engines, and then explain why automobiles use piston engines instead of gas turbine engines.

(5%)

b) Explain why high-bypass turbofans are generally used for commercial passenger aircraft, instead of turbojets (low-bypass gas turbine engine).

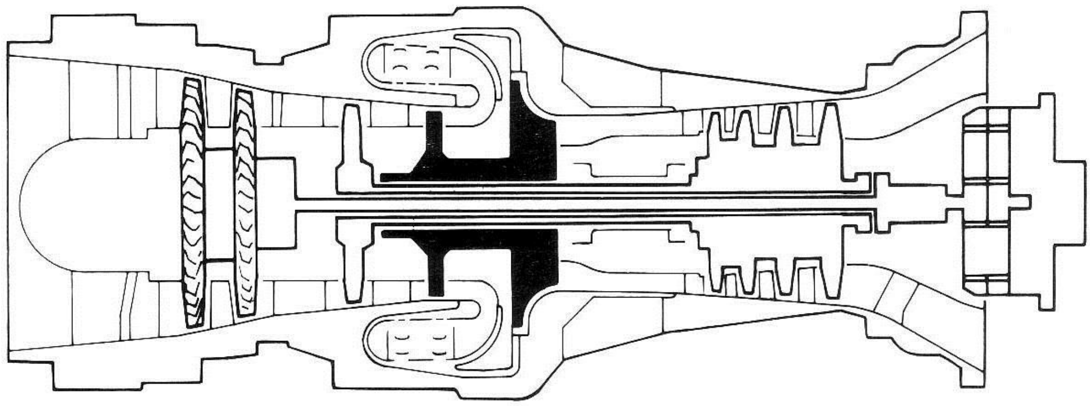
(2%)

c) Many modern helicopters are also powered by gas turbine engines. Would high-bypass turbofans be suitable for helicopters? Why / why not?

(3%)

Question 4 (15%)

Consider the gas turbine engine shown below.



a) Describe the basic configuration of the engine, including:

- Direction of airflow (Left→Right or Right→Left)
- Compressor type(s), including number of stages.
- Number of turbine stages

(5%)

b) How many separate shafts does the engine have?
Describe the function of each separate shaft.

(3%)

c) Is this engine designed for propulsion via exhaust gases? Explain your answer.

(2%)

d) Explain the two main functions of stators in axial compressors, with reference to their effect on the air-stream as it progresses through the compressor.

(5%)

Section B

Total Number of Marks for this section: 50%

Question 5 (15%)

An SI engine is operating on the air-standard Otto cycle at WOT at 2500 RPM. Pressure and temperature at the cylinder at the start of compression are 90 kPa and 50°C respectively.
The following parameters apply to the engine:

- Compression ratio = 9.8
- Crevice volume = 3.5% of Clearance Volume
- Crevice temperature = constant at 160°C
- Crevice pressure = equal to instantaneous cylinder pressure
- Mass flow rate of fuel into engine = 0.0061 kg/s
- Percentage of fuel mass trapped in crevice that exits exhaust unburned = 21%
- Fuel type = gasoline

Determine:

(a) The percentage of fuel trapped in the crevice volume at the end of compression.

(5%)

(b) Mass flow rate of unburned fuel in exhaust due to crevice volume, in kg/hr.

(5%)

(c) Rate of chemical energy loss in exhaust due to this unburned fuel, in kW.

(5%)

Question 6 (10%)

A 2 cylinder 2-stroke SI engine is operating on an air-standard cycle. Peak pressure and temperature within the cylinder are 8200 kPa and 3200°C respectively. The temperature within the cylinder just before exhaust blowdown occurs is 1350°C.

Determine:

(a) Cylinder pressure just before exhaust blowdown occurs, in kPa.

(5%)

(b) Maximum flow velocity through the exhaust port, in m/s.

(5%)

Question 7 (15%)

A compression ignition engine operates on a dual diesel cycle with a compression ratio of 22:1. To ensure engine longevity, the maximum pressure to be developed in the engine is 10,000 kPa. Light diesel fuel at an AF ratio of 22:1 is used with a combustion efficiency of 98%. The temperature and pressure of the mixture at the start of compression are 50°C and 98 kPa. The use of common rail diesel technology on this engine allows for the variation of the cut-off and pressure ratios by electronically altering the injection timing.

a) By varying the cut-off and pressure ratios, what is the maximum thermal efficiency possible under these conditions? (10%)

b) What is the maximum cycle temperature achieved under these conditions (in part a)? (5%)

Question 8 (10%)

Small gas turbines, say less than 500kW, generally use one or two stages of centrifugal compressor rather than axial flow compressors, whereas large mass flow rate, high pressure ratio gas turbines use axial flow compressors exclusively.

a) What are the advantages offered by centrifugal compressors over axial flow compressors and why are they preferred in small gas turbines? (2%)

b) Why do axial flow compressors become necessary as flow rate and pressure ratio increase? (3%)

c) What are the three most common methods of increasing the operating speed range of the gas turbine which also assist in the prevention of compressor stall? (5%)

CHARLES DARWIN UNIVERSITY
SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY

ENG482 ENGINES AND TURBOMACHINERY

DATA AND FORMULAE SHEET

NOTATION

Notation, symbols, and abbreviations used in this text. Common units are given in brackets, both SI and Imperial English.

A	Cross-section area of flow [cm^2] [$in.^2$]
A_c	Flow area of fuel capillary tube [mm^2] [$in.^2$]
A_{cc}	Surface area of combustion chamber [cm^2] [$in.^2$]
A_{ch}	Cylinder head surface area [cm^2] [$in.^2$]
A_{ex}	Area of exhaust valve [cm^2] [$in.^2$]
A_i	Area of intake valve [cm^2] [$in.^2$]
A_p	Piston face area of flat-faced piston, or cross-section area of cylinder
A_t	Throat area of carburetor [cm^2] [$in.^2$]
AF	Air-fuel ratio [kg_a/kg_f] [lbm_a/lbm_f]
AKI	Anti-knock index
AON	Aviation octane number
B	Cylinder bore [cm] [in.]
C	Constant
C_D	Discharge coefficient
C_{Dc}	Discharge coefficient of capillary tube
C_{Dt}	Discharge coefficient of carburetor throat
CI	Cetane index
CN	Cetane number
Eff	Aftercooler effectiveness
EGR	Exhaust gas recycle [%]
F	Force [N] [lbf]
F_f	Friction force [N] [lbf]
F_r	Force of connecting rod [N] [lbf]
F_x	Forces in the X direction [N] [lbf]
F_y	Forces in the Y direction [N] [lbf]
$F_{1\text{-}2}$	View factor
FA	Fuel-air ratio [kg_f/kg_a] [lbm_f/lbm_a]
FS	Fuel sensitivity
I	Moment of inertia [kg-m^2] [lbm-ft^2]
ID	Ignition delay [sec]
K_e	Chemical equilibrium constant
M	Molecular weight (molar mass) [kg/kgmole] [lbm/lbmmole]
MON	Motor octane number
N	Engine speed [RPM]

N	Number of moles
N_c	Number of cylinders
N_v	Moles of vapor
Nu	Nusselt number
ON	Octane number
P	Pressure [kPa] [atm] [psi]
P_a	Air pressure [kPa] [atm] [psi]
P_{ex}	Exhaust pressure [kPa] [atm] [psi]
P_{EVO}	Pressure when the exhaust valve opens [kPa] [psi]
P_f	Fuel pressure [kPa] [atm] [psi]
P_i	Intake pressure [kPa] [atm] [psi]
P_{inj}	Injection pressure [kPa] [atm] [psi]
P_o	Standard pressure [kPa] [atm] [psi]
P_t	Pressure in carburetor throat [kPa] [atm] [psi]
P_v	Vapor pressure [kPa] [atm] [psi]
Q	Heat transfer [kJ] [BTU]
$\dot{Q}$	Heat transfer rate [kW] [hp] [BTU/sec]
Q_{HHV}	Higher heating value [kJ/kg] [BTU/lbm]
Q_{HV}	Heating value of fuel [kJ/kg] [BTU/lbm]
Q_{LHV}	Lower heating value [kJ/kg] [BTU/lbm]
R	Ratio of connecting rod length to crank offset
R	Gas constant [kJ/kg-K] [ft-lbf/lbm-°R] [BTU/lbm-°R]
Re	Reynolds number
RON	Research octane number
S	Stroke length [cm] [in.]
S_g	Specific gravity
SOF	Soluble organic fraction
SR	Swirl ratio
T	Temperature [°C] [K] [°F] [°R]
T_a	Temperature of air [°C] [K] [°F] [°R]
T_c	Temperature of coolant [°C] [K] [°F] [°R]
T_{EVO}	Temperature when the exhaust valve opens [°C] [K] [°F] [°R]
T_{ex}	Temperature of exhaust [°C] [K] [°F] [°R]
T_g	Temperature of gas [°C] [K] [°F] [°R]
T_i	Intake temperature [°C] [K] [°F] [°R]
T_m	Temperature of mixture [°C] [K] [°F] [°R]
T_{mp}	Midpoint boiling temperature in °F [°F]
T_o	Standard temperature [°C] [°F]
T_w	Wall temperature [°C] [K] [°F] [°R]
TR	Tumble ratio
U_p	Piston speed [m/sec] [ft/sec]
$\dot{U}_p$	Average piston speed [m/sec] [ft/sec]
V	Cylinder volume [L] [cm^3] [in.^{3}]

V_{BDC}	Cylinder volume at bottom dead centre [L] [cm^3] [in.^{3}]
V_c	Clearance volume [L] [cm^3] [in.^{3}]
V_d	Displacement volume [L] [cm^3] [in.^{3}]
V_{TDC}	Cylinder volume at top dead centre [L] [cm^3] [in.^{3}]
W	Work [kJ] [ft-lbf] [BTU]
W_b	Brake work [kJ] [ft-lbf] [BTU]
W_f	Friction work [kJ] [ft-lbf] [BTU]
W_i	Indicated work [kJ] [ft-lbf] [BTU]
$\dot{W}$	Power [kW] [hp]
$\dot{W}_b$	Brake power [kW] [hp] Power to drive compressor [kW] [hp]
$\dot{W}_f$	Friction power [kW] [hp]
$\dot{W}_i$	Indicated power [kW] [hp]
$\dot{W}_m$	Power to motor engine [kW] [hp]
$\dot{W}_{sc}$	Power to drive supercharger [kW] [hp]
$\dot{W}_t$	Turbine power [kW] [hp]
a	Crank offset (crank radius) [cm] [in.]
c	Speed of sound [m/sec] [ft/sec]
c_{ex}	Speed of sound at exhaust conditions [m/sec] [ft/sec]
c_i	Speed of sound at inlet conditions [m/sec] [ft/sec]
c_o	Speed of sound at ambient conditions [m/sec] [ft/sec]
c_p	Specific heat at constant pressure [kJ/kg-K] [BTU/lbm-°R]
c_v	Specific heat at constant volume [kJ/kg-K] [BTU/lbm-°R]
d_v	Valve diameter [cm] [in.]
dB	Decibel
g	Acceleration due to gravity [m/sec^2] [ft/sec^2]
h	Height differential in fuel capillary tube [cm] [in.]
h	Convection heat transfer coefficient [kW/m^2-K] [BTU/hr-ft^2-°R]
$\underline{h}$	Specific enthalpy [kJ/kg] [BTU/lbm]
h_a	Specific enthalpy of air [kJ/kg] [BTU/lbm]
h_c	Convection heat transfer coefficient on the coolant side [kW/m^2-K] [BTU/hr-ft^2-°R]
h_{ex}	Specific enthalpy of exhaust [kJ/kg] [BTU/lbm]
h_g	Convection heat transfer coefficient on the gas side [kW/m^2-K] [BTU/hr-ft^2-°R]
h_m	Specific enthalpy of mixture [kJ/kg] [BTU/lbm]
h_f^o	Enthalpy of formation [kJ/kgmole] [BTU/lbmmole]
Δh	Change in enthalpy from standard conditions [kJ/kgmole]
k	Ratio of specific heats
k	Thermal conductivity [kW/m-K] [BTU/hr-ft-°R]
k_g	Thermal conductivity of gas [kW/m-K] [BTU/hr-ft-°R]

l	Valve lift [cm] [in.]
m	Mass [kg] [lbm]
m_a	Mass of air [kg] [lbm]
m_{ex}	Mass of exhaust [kg] [lbm]
m_f	Mass of fuel [kg] [lbm]
m_m	Mass of gas mixture [kg] [lbm]
m_{mi}	Mass of mixture ingested [kg] [lbm]
m_{mt}	Mass of mixture trapped [kg] [lbm]
m_{tc}	Mass of total charge trapped [kg] [lbm]
$\dot{m}$	Mass flow rate [kg/sec] [lbm/sec]
$\dot{m}_a$	Mass flow rate of air [kg/sec] [lbm/sec]
$\dot{m}_{EGR}$	Mass flow rate of exhaust gas recycle [kg/sec] [lbm/sec]
$\dot{m}_f$	Mass flow rate of fuel [kg/sec] [lbm/sec]
$\dot{m}_i$	Mass flow into the cylinder [kg/sec] [lbm/sec]
mep	Mean effective pressure [kPa] [atm] [psi]
n	Number of revolutions per cycle
q	Heat transfer per unit mass [kJ/kg] [BTU/lbm]
q	Heat transfer per unit area [kJ/m^2] [BTU/ft^2]
$\dot{q}$	Heat transfer rate per unit mass [kW/kg] [BTU/hr-lbm]
$\dot{q}$	Heat transfer rate per unit area [kJ/m^2] [BTU/ft^2]
r	Connecting rod length [cm] [in.]
r_c	Compression ratio
r_e	Expansion ratio
rh	Relative humidity [%]
s	Distance between wrist pin and crankshaft axis [cm] [in.]
t	Time [sec]
u	Specific internal energy [kJ/kg] [BTU/lbm]
u_t	Swirl tangential speed [m/sec] [ft/sec]
v	Specific volume [m^3/kg] [ft^3/lbm]
v_{BDC}	Specific volume at bottom dead centre [m^3/kg] [ft^3/lbm]
v_{ex}	Specific volume of exhaust [m^3/kg] [ft^3/lbm]
v_{TDC}	Specific volume at top dead centre [m^3/kg] [ft^3/lbm]
w	Specific work [kJ/kg] [ft-lbf/lbm][BTU/lbm]
w_b	Brake-specific work [kJ/kg] [ft-lbf/lbm] [BTU/lbm]
w_f	Friction-specific work [kJ/kg] [ft-lbf/lbm] [BTU/lbm]
w_i	Indicated-specific work [kJ/kg] [ft-lbf/lbm] [BTU/lbm]
x	Distance [cm] [m] [in.] [ft]
x_{ex}	Fraction of exhaust
x_r	Exhaust residual
x_v	Mole fraction of water vapour
α	Pressure ratio

α	Ratio of valve areas
β	Cutoff ratio
Γ	Angular momentum [kg-m^2/sec] [lbm-ft^2/sec]
ε_g	Emissivity of gas
ε_w	Emissivity of wall
η_c	Combustion efficiency [%]
η_f	Fuel conversion efficiency [%]
η_m	Mechanical efficiency [%]
η_s	Isentropic efficiency [%]
η_t	Thermal efficiency [%]
η_v	Volumetric efficiency of the engine [%]
θ	Crank angle measured from TDC [°]
λ	Lambda value
λ_{ce}	Charging efficiency
λ_{dr}	Delivery ratio
λ_{rc}	Relative charge
λ_{se}	Scavenging efficiency
λ_{te}	Trapping efficiency
μ	Dynamic viscosity [kg/m-sec] [lbm/ft-sec]
μ_g	Dynamic viscosity of gas [kg/m-sec] [lbm/ft-sec]
v	Stoichiometric coefficients
ρ	Density [kg/m^3] [lbm/ft^3]
ρ_a	Density of air [kg/m^3] [lbm/ft^3]
ρ_o	Density of air at standard conditions [kg/m^3] [lbm/ft^3]
ρ_f	Density of fuel [kg/m^3] [lbm/ft^3]
σ	Stefan-Boltzmann constant [W/m^2-K^4] [BTU/hr-ft^2-°R^4]
τ	Torque [N-m] [lbf-ft]
τ_s	Shear force per unit area [N/m^2] [lbf/ft^2]
φ	Equivalence ratio
φ	Angle between connecting rod and centre-line of the cylinder
ω	Angular velocity of swirl [rev/sec]
ω_t	Angular velocity of tumble [rev/sec]
ω_v	Specific humidity [kg$_v$/kg$_a$] [grains$_v$/lbm$_a$]

FORMULAE

$\overline{U_p} = 2SN$

$V = Vc + (\pi B^2/4)(r + a - s)$

τ = (bmep) $V_d / 2\pi$ (two-stroke cycle)

τ = (bmep) $V_d / 4\pi$ (four-stroke cycle)

AF $= m_a / m_f = \dot{m}_a / \dot{m}_f$

FA $= m_f / m_a = \dot{m}_f / \dot{m}_a = 1 /$ AF

$\varphi = (\text{FA})_{act} / (\text{FA})_{stoich} = (\text{AF})_{stoich} / (\text{AF})_{act}$

$\eta_m = \dot{W}_b / \dot{W}_i = (\dot{m}_f \dot{W}_I) / (\dot{m}_f \dot{W}_b)$ = (isfc / (bsfc)

$Q_{in} = m_f \, Q_{HV} \, \eta_c$

$\eta_t = W / Q_{in} = \dot{W}_b / \dot{Q}_{in} = \dot{W} / \dot{m}_f Q_{HV} \eta_c = \eta_f / \eta_c$

$\eta_v = m_a / p_a V_d$

$\eta_v = n \, \dot{m}_a / p_a V_d N$

$\tau = \eta_f / \eta_v V_d Q_{HVpa} (\text{FA}) / 2\pi n$

$\dot{W}_b = \eta_f / \eta_v N V_d \, Q_{HVpa} (\text{FA}) / n$

$Pv = RT$

$PV = mRT$

$P = \rho RT$

$dh = c_p \, dT$

$du = c_v \, dT$

Pvk = constant isentropic process

Tv^{k-1} = constant isentropic process

$TP^{(k-1)/k}$ = constant isentropic process

$w_{1-2} = (P_2 v_2 - P_1 v_1) / (1 - k)$ isentropic work in closed system

$= R (T_2 - T_1) / (1 - k)$

c_p = 1.005 kJ/kg-K

c_v = 0.718 kJ/kg-K

$k = c_p / c_v$

$R = c_p - c_v =$ 0.287 kJ/kg-K

$\beta = V_3 / V_2 = v_3 / v_2 = T_3 / T_2$

$(\eta_t)_{DIESEL} = 1 - (1/r_c)^{k-1} [(\beta^k - 1) / \{k(\beta - 1)\}]$

$C_8H_{18} + 12.5O_2 \rightarrow 8CO_2 + 9H_2O$

$C_8H_{18} + 12.5O_2 + 12.5(3.76)N_2 \rightarrow 8CO_2 + 9H_2O + 12.5(3.76)N_2$

AKI = (MON + RON) / 2

FS = RON - MON